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POSSIBLE EFFECTS OF SAMPLING BIASES ON REPRODUCTION RATE ESTIMATES FOR DOLPHINS IN THE EASTERN TROPICAL PACIFIC

Tom Polacheck

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U.S. DEPARTMENT OF COMMERCE
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Southwest Fisheries Center

NOAA Technical Memorandum NMFS

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POSSIBLE EFFECTS OF SAMPLING BIASES
ON REPRODUCTION RATE ESTIMATES FOR
DOLPHIN IN THE EASTERN TROPICAL PACIFIC

by

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INTRODUCTION

The only available information on the life history parameters for dolphin populations in the eastern tropical Pacific is derived from animals incidentally killed during yellowfin tuna purse seine operations. Because of the methods by which these samples have been obtained and apparent inconsistencies in some of the estimated life history parameters, the question of potential biases in these samples has been raised (Powers and Barlow, 1979[1]).

Young calves and lactating females may be more vulnerable than other animals during purse seining operations. Analysis of the proportion of immature females of the total number of dolphins killed in a set supports the suggestion that the overall sample for the spotted dolphin (Stenella attenuata) may be biased towards immature animals (Powers and Barlow, 1979[1]). Similar analysis for the data on the eastern spinner and northern whitebelly spinner dolphin (Stenella longirostris) did not reveal any significant differences, although a trend did exist. In an attempt to correct for this bias, the life history parameters for S. attenuata have been estimated only from sets in which more than forty dolphins have been killed, based on the assumption that large kills should tend to be unselective

[1]Powers, J. E. and J. Barlow. 1979. Biases in the tuna-net sampling of dolphins in the eastern tropical Pacific, SOPS/79/31. Working paper, SOPS/79/31 Status of Porpoise Stocks Workshop, Southwest Fisheries Center, La Jolla, California.

(Henderson, et al., 1979[2]). However, the question of possible biases still remains as a number of the estimated life history parameters appears inconsistent (e.g., Polacheck, in prep. a and b[3]).

The purpose of this report is to present a sensitivity analysis on the effects that biased sampling of young calves and lactating females would have on the various estimated life history parameters. This sensitivity analysis provides one measure of the reliability of the various estimates. Also, where inconsistencies in the estimates can be identified, this analysis provides one means for evaluating which estimates are likely in error.

METHODS

The effects of sampling biases toward nursing pairs (i.e., lactating females with their calves) and immature calves were explored by developing a simple model for the number of animals in each category which would have been in the sample in the absence of the selective factor. These "corrected" observations were then used to compute corrected values for the proportion mature, the sex ratio, the ratio of lactating to immature females, the pregnancy rate and the gross annual reproduction rate. The following symbols will be useful in defining how the analysis was conducted. Let:

b_1 = the proportional bias or increased vulnerability of nursing pairs

b_2 = the proportional bias or increased vulnerability of immature calves in addition to b_1.

P = the number of pregnant females in a sample
R = the number of resting females
L = the number of lactating females
C = the number of lactating and pregnant females
U = the number of mature females unclassified with respect to reproductive condition
I = the number of immature females
N = the number of nursing calves

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[2]Henderson, J., W. F. Perrin and R. B. Miller. 1979. Gross annual production dolphin populations (Stenella spp.) in the eastern tropical Pacific, SOPS/79/33. Working paper, SOPS/79/33 Status of Porpoise Stocks Workshop, Southwest Fisheries Center, La Jolla, California.

[3]Polacheck, T. In prep. a. Estimating current rates of increase and survival rates from reproductive data for dolphin populations in the eastern tropical Pacific. NOAA Technical Memorandum, NMFS-SWFC.

Polacheck, T. In prep. b. Juvenile survival rates as estimated from the proportion of immature females that are nursing for dolphin stocks in the eastern tropical Pacific. NOAA Technical Memorandum, NMFS-SWFC.

M = the number of males

The subscript c will be used with the above symbols to designate the sample values corrected for biases b_1 and b_2, and the subscript o to designate the observed sample values. Accounting for biases b_1 and b_2, the corrected number in the various reproductive states can be modeled as:

$$P_c = P_o \tag{1}$$

$$R_c = R_o \tag{2}$$

$$L_c = \frac{1}{1+b_1} L_o \tag{3}$$

$$C_c = \frac{1}{1+b_1} C_o \tag{4}$$

$$U_c = U_o - U_o \left(\frac{b_1}{1+b_1}\right) \left(\frac{L_o + C_o}{L_o + C_o + P_o + R_o}\right) \tag{5}$$

$$I_c = \frac{1}{1+b_2} \left(I_o - \frac{.5b_1}{1+b_1} \left(L_o + C_o + U_o \left(\frac{L_o + C_o}{L_o + C_o + P_o + R_o}\right)\right)\right) \tag{6}$$

$$M_c = M_o - (I_o - I_c) \tag{7}$$

Equations 5 and 6 assume that the proportion of undetermined sexually mature females that are in the various reproductive states is equal to the proportion for which the reproduction states were determined. Equations 6 and 7 assume that the sex ratio of nursing calves is .5 and equation 7 assumes that the sex ratio of all immature calves is .5.

Estimates of the proportion mature, the sex ratio, the ratio of lactating to immature females, the pregnancy rate as estimated by Method 1 (see Henderson et al., 1979[2]), and the gross annual reproduction rate (G.A.R.) were calculated using the corrected values for the observed number in each reproductive condition for a range of values for b_1 and b_2. The analysis was conducted on the five stocks for which the observed numbers in each reproductive state are available (Henderson, et al., 1979[2]).

The sensitivity of Henderson's Method 2 for estimating pregnancy rates was also considered. Recalculating the pregnancy rate as estimated by Method 2 to account for bias is not straightforward. However, bias b_1 should not introduce a bias into the Method II estimates of pregnancy rate. In order to assess the effect of bias b_2, it was assumed that this bias only applied to nursing calves. The number of nursing calves when b_2 is corrected for should equal the number of lactating females. Therefore, the number of nursing calves actually occurring in the sample should equal:

$$N_o = (1 + b_2)\ N_c = (1 + b_2)\ L_c$$

It was further assumed, as it is in Method 2, that the first N_o individuals in the observed cummulative length-frequency distribution represent nursing calves. In order to assess the effect of bias, $(b_2/1 + b_2) \times N_o$ individuals were randomly removed from the length distribution of nursing calves and the Method 2 pregnancy estimate was recalculated. Since this method of assessing the effect of b_2 is a stochastic procedure, for each value b_2 examined the procedure was repeated 10 times. The mean and standard deviations of these replications calculated. The standard deviations of these calculations were on the order of 10^{10} or less and therefore only the means are reported below.

RESULTS AND DISCUSSION

The estimated life history parameters using the corrected sample values for the number of males and for the numbers of females lactating, unclassified, and immature and male from equations 3 to 7 are given in Appendix Tables 1 to 5 for five populations of dolphin. New estimates are given based on a range of values for the proportional biases b_1, and b_2. For the northern and southern offshore spotted dolphin populations and the northern and southern whitebelly spinner dolphin populations, values are given in Tables 1, 2, 4 and 5, respectively, for the proportion of females that are mature, the proportion of calves which are nursing, the proportion of the population which is female, the pregnancy rate estimated by Method 1, and the estimated gross annual reproduction rate using this pregnancy rate. For the eastern spinner porpoise population, the above calculations are given in Table 3, along with estimates of pregnancy rates and gross annual reproduction rates using Method 2. These latter were computed using the simulation technique described above. Due to limitations on computer time these simulations were not completed for the other populations.

In Figures 1 to 7, the results for the eastern spinner population (Stenella longirostris) have been plotted for each of the reproductive estimators, illustrating the general behavior of each of the estimators to bias b_1 and b_2. Method 1 pregnancy rates and the proportion of immature calves nursing are the most sensitive estimators to bias b_1. Method 2 pregnancy rates, the proportion of mature females and proportion of immature calves nursing are the estimators most sensitive to b_2. Method 2 pregnancy rates tend to be more sensitive to bias b_2 than Method 1 pregnancy rates are to bias b_1 of an equal magnitude. Somewhat surprising is the insensitivity to bias of the G.A.R. for both Methods 1 and 2 pregnancy rates. A bias of 100% in sampling nursing pairs results in a change of about 1% in the estimated G.A.R. for the eastern spinner stock for both methods, while a bias of a similar magnitude in sampling immature females results in a change of at most 3%. The reason for this insensitivity is that the G.A.R. is a product of the percent female, the percent mature and the pregnancy rate. For both methods, the effects of b_1 and b_2 on these parameters either tend to be small and/or opposite in magnitude.

The results of this sensitivity analysis can be used to suggest where likely biases may exist in the reproductive samples when inconsistencies in these estimates are identified. This will be illustrated using the results for the eastern spinner dolphin population, where the following three inconsistencies have been identified in the reproductive estimators:

1. The pregnancy rate as estimated by Method 1 should be greater than or equal to the rate estimated by Method 2 (Goodman, unpublished manuscript; Polacheck, unpublished manuscript).

2. The observed proportion of females that are mature, given current estimates of the age of maturity and either Method 1 or 2 estimates of pregnancy rates, is likely only to be observed in a rapidly declining population. In a viable population, given the present estimates of age of maturity and pregnancy rates, this proportion would be significantly greater (Polacheck, in prep a[3]).

3. For a nondeclining population, given the current range of estimates for the age of weaning based on Method 1 and the age of maturation, the observed proportion of immatures that are nursing is also too low (Polacheck, in prep b[3]).

Inconsistency 1 can be reconciled by either b_1 or b_2 although the necessary magnitude of b_1 is over a third greater than for b_2 (i.e. .95 compared to .60). A bias of b_2 sufficient to reconcile the two pregnancy rate estimates would be sufficient to reconcile inconsistencies 2 and 3. In attempting to evaluate whether biases b_1 or b_2 can reconcile inconsistencies 2 and 3, it is not sufficient to look only at their effects on the estimated proportion mature or estimated proportion nursing since these inconsistencies are also sensitive to other estimated parameters which could be affected by these biases. Thus, both an increase in the estimated proportion mature or in the pregnancy rate would tend to reconcile inconsistency 2 (Polacheck, in prep a[3]). However, accounting for a bias b_1 would increase the pregnancy rate (Method 1) and decrease the proportion mature while bias b_2 would have just the opposite effect. It appears that for the values of the observed estimates and their sensitivity to bias, increasing the proportion mature would be the dominant factor. Therefore only bias b_2 is likely to account for this inconsistency. Similarly, inconsistency 3 can be reconciled by a decrease in the age of weaning or an increase in the proportion mature (Polacheck, in prep b[3]). While not considered in this paper, biases b_1 and b_2 could both affect the estimated age of weaning. The age of weaning or the length of lactation have been estimated in two ways. Accounting for bias of type b_2 would increase the estimate of the proportion nursing and either not affect or decrease the age of weaning (Polacheck, in prep b[3]). Therefore, bias b_2 could explain inconsistency 2. Accounting for bias b_1 could also result in a decrease in the age of weaning. However, accounting for bias b_1 would also result in a decrease in the proportion nursing. The potential for a decrease in the age of weaning due to b_1 is probably insufficient to counterbalance the decrease in the proportion nursing. Thus, bias b_1 is unlikely to be able to account for this inconsistency. The results of this sensitivity analysis combined with the three inconsistencies identified above would suggest that the observed samples for the eastern spinner stock are likely to be biased in the overrepresentation of immature animals. Given the large magnitude of b_2 necessary to reconcile the two pregnancy rate estimates, if this is the only factor contributing to the inconsistency, it is possible that a combination of both b_1 and b_2 may be occurring in the sample, although in order to reconcile the other two biases, b_2 must be the dominant bias.

It is possible that other biases than those considered here could be operating. For instance, it is possible that pregnant females are under-represented in the observed samples. Alternatively, the seasonal nature of the samples combined with the known marked seasonality in breeding (Barlow, 1979[4]) may be introducing bias. Barlow (1979[4]) explored the possible effect that this factor might have on Method 1 pregnancy rate estimates and concluded that it would be small given the long length of gestation. The effect of this factor on Method 2 pregnancy rate estimates is not obvious, but it could be that little sampling occurs when a high proportion of the calves are approaching the age of weaning.

The above apparent inconsistencies in the data for the eastern spinner porpoise population are either non-existent or not as strong for the other porpoise populations in the eastern tropical Pacific for which reproductive data are available. This fact, combined with the results of Powers and Barlow (1979[1]) on possible bias in these samples, suggests that the sampling process is nonuniform across stocks. In particular, the question of what factors could explain the large bias suggested by this paper that are unique in the

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[4]Barlow, J. 1979. Reproductive seasonality in pelagic dolphins of the eastern tropical Pacific, SOPS/79/26. Working paper, SOPS/79/26 Status of Porpoise Stocks Workshop, Southwest Fisheries Center, La Jolla, California.

capture and sampling of eastern spinner needs to be explored. Stuntz (1980[5]) suggested that a possible factor could be that most eastern spinners are captured in mixed aggregations with spotted dolphin and apparently occupy a subordinate position within the purse seine. However, there is no direct evidence that this results in biased samples. Questions such as this need to be considered before the representativeness of the kill samples can be fully assessed.

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[5]Stuntz, W. E. 1980. Variation in age structure of the incidental kill of spotted dolphins, _Stenella attenuata_, in the U.S. tropical purse-seine fishery. _Southwest Fisheries Center Admin. Report_ No. LJ-80-06.

APPENDIX

Tables of the sensitivity of the various reproductive estimates to biases b_1 and b_2 for five stocks of porpoises in the eastern tropical Pacific. The observed estimates for each stock are based on the pooled data set from 1973-1978 (Henderson, et al, 1979).

Table 1. Effects of bias b_1 and b_2 on the various reproductive estimators for the northern offshore spotted dolphin population (S. attenuata).

1a. Proportion of mature females.

B_1	Value of B_2 0.00	0.20	0.40	0.60	0.80	1.00
0.000	0.565	0.609	0.645	0.675	0.700	0.722
0.200	0.556	0.601	0.637	0.667	0.693	0.715
0.400	0.550	0.594	0.631	0.662	0.687	0.710
0.600	0.544	0.589	0.626	0.657	0.683	0.705
0.800	0.540	0.585	0.621	0.652	0.679	0.701
1.000	0.536	0.581	0.618	0.649	0.675	0.698

1b. Proportion of nursing calves.

B_1	Value of B_2 0.00	0.20	0.40	0.60	0.80	1.00
0.000	0.337	0.405	0.472	0.539	0.607	0.674
0.200	0.298	0.357	0.417	0.476	0.536	0.595
0.400	0.266	0.320	0.373	0.426	0.480	0.533
0.600	0.241	0.289	0.338	0.386	0.434	0.482
0.800	0.220	0.264	0.308	0.352	0.397	0.441
1.000	0.203	0.243	0.284	0.324	0.365	0.405

1c. Proportion female.

B_1	Value of B_2 0.00	0.20	0.40	0.60	0.80	1.00
0.000	0.556	0.561	0.565	0.568	0.571	0.573
0.200	0.545	0.548	0.552	0.554	0.557	0.559
0.400	0.536	0.539	0.541	0.544	0.545	0.547
0.600	0.529	0.531	0.533	0.535	0.536	0.538
0.800	0.523	0.525	0.526	0.528	0.529	0.530
1.000	0.518	0.519	0.521	0.522	0.523	0.523

1d. Method 1 pregnancy rate.

Value of B_1	
0.000	0.375
0.200	0.403
0.400	0.426
0.600	0.446
0.800	0.462
1.000	0.477

1e. G.A.R. using Method 1 pregnancy rates.

B_1	Value of B_2 0.00	0.20	0.40	0.60	0.80	1.00
0.000	0.118	0.128	0.137	0.144	0.150	0.155
0.200	0.122	0.133	0.142	0.149	0.155	0.161
0.400	0.125	0.136	0.145	0.153	0.160	0.165
0.600	0.128	0.139	0.149	0.156	0.163	0.169
0.800	0.130	0.142	0.151	0.159	0.166	0.172
1.000	0.132	0.144	0.153	0.162	0.168	0.174

Table 2. Effects of bias b_1 and b_2 on the various reproductive estimators for the southern offshore spotted dolphin population (S. attenuata).

2a. Proportion of mature females.

B_1	Value of B_2 0.00	0.20	0.40	0.60	0.80	1.00
0.000	0.673	0.711	0.742	0.767	0.787	0.804
0.200	0.673	0.712	0.742	0.767	0.788	0.805
0.400	0.674	0.712	0.743	0.767	0.788	0.805
0.600	0.674	0.713	0.743	0.768	0.788	0.805
0.800	0.674	0.713	0.743	0.768	0.788	0.805
1.000	0.674	0.713	0.744	0.768	0.788	0.806

2b. Proportion of nursing calves.

B_1	Value of B_2 0.00	0.20	0.40	0.60	0.80	1.00
0.000	0.464	0.557	0.650	0.743	0.836	0.928
0.200	0.419	0.503	0.587	0.671	0.755	0.839
0.400	0.382	0.459	0.535	0.612	0.688	0.765
0.600	0.351	0.422	0.492	0.562	0.632	0.703
0.800	0.325	0.390	0.455	0.520	0.585	0.650
1.000	0.302	0.363	0.423	0.484	0.544	0.605

2c. Proportion female.

B_1	Value of B_2 0.00	0.20	0.40	0.60	0.80	1.00
0.000	0.594	0.600	0.605	0.610	0.613	0.616
0.200	0.584	0.589	0.594	0.598	0.601	0.603
0.400	0.576	0.581	0.585	0.588	0.591	0.593
0.600	0.569	0.574	0.577	0.580	0.583	0.585
0.800	0.564	0.568	0.571	0.574	0.576	0.578
1.000	0.559	0.563	0.566	0.569	0.571	0.572

2d. Method 1 pregnancy rate.

Value of B_1	
0.000	0.572
0.200	0.597
0.400	0.617
0.600	0.634
0.800	0.649
1.000	0.661

2e. G.A.R. using Method 1 pregnancy rates.

B_1	Value of B_2 0.00	0.20	0.40	0.60	0.80	1.00
0.000	0.228	0.244	0.257	0.267	0.276	0.283
0.200	0.234	0.250	0.263	0.274	0.282	0.290
0.400	0.239	0.255	0.268	0.279	0.287	0.295
0.600	0.243	0.259	0.272	0.283	0.291	0.299
0.800	0.247	0.263	0.275	0.286	0.295	0.302
1.000	0.249	0.265	0.278	0.289	0.297	0.305

Table 3. Effects of bias b_1 and b_2 on various reproductive estimators for the eastern spinner dolphin population (*S. longirostris*).

3a. Proportion of mature females.

B_1	Value of B_2 0.00	0.20	0.40	0.60	0.80	1.00
0.000	0.437	0.482	0.521	0.554	0.583	0.608
0.200	0.422	0.467	0.506	0.539	0.568	0.594
0.400	0.411	0.456	0.494	0.527	0.557	0.582
0.600	0.402	0.446	0.484	0.518	0.547	0.573
0.800	0.394	0.438	0.476	0.510	0.539	0.565
1.000	0.387	0.431	0.470	0.503	0.532	0.558

3b. Proportion of nursing calves.

B_1	Value of B_2 0.00	0.20	0.40	0.60	0.80	1.00
0.000	0.210	0.252	0.294	0.336	0.378	0.420
0.200	0.181	0.217	0.254	0.290	0.326	0.362
0.400	0.159	0.191	0.223	0.255	0.287	0.319
0.600	0.142	0.171	0.199	0.228	0.256	0.285
0.800	0.129	0.154	0.180	0.206	0.231	0.257
1.000	0.117	0.141	0.164	0.188	0.211	0.234

3c. Proportion female.

B_1	Value of B_2 0.00	0.20	0.40	0.60	0.80	1.00
0.000	0.506	0.507	0.508	0.508	0.509	0.509
0.200	0.496	0.496	0.496	0.495	0.495	0.495
0.400	0.489	0.487	0.486	0.485	0.485	0.484
0.600	0.482	0.481	0.479	0.478	0.476	0.475
0.800	0.477	0.475	0.473	0.471	0.470	0.468
1.000	0.473	0.471	0.468	0.466	0.464	0.462

3d. Method 1 pregnancy rate.

Value of B_1	
0.000	0.336
0.200	0.367
0.400	0.393
0.600	0.415
0.800	0.434
1.000	0.451

3e. G.A.R. using Method 1 pregnancy rates.

B_1	Value of B_2 0.00	0.20	0.40	0.60	0.80	1.00
0.000	0.074	0.082	0.089	0.095	0.100	0.104
0.200	0.077	0.085	0.092	0.098	0.103	0.108
0.400	0.079	0.087	0.094	0.101	0.106	0.111
0.600	0.080	0.089	0.096	0.103	0.108	0.113
0.800	0.082	0.090	0.098	0.104	0.110	0.115
1.000	0.083	0.091	0.099	0.106	0.111	0.116

Table 3. (continued)

3f. Method 2 pregnancy rate.

B_1	Value of B_2 0.00	0.20	0.40	0.60	0.80	1.00
0.000	0.447	0.420	0.381	0.342	0.318	0.301

3g. G.A.R. using Method 2 pregnancy rates.

B_1	Value of B_2 0.00	0.20	0.40	0.60	0.80	1.00
0.000	0.099	0.103	0.101	0.096	0.094	0.093
0.200	0.094	0.097	0.096	0.091	0.089	0.089
0.400	0.090	0.093	0.091	0.087	0.086	0.085
0.600	0.087	0.090	0.088	0.085	0.083	0.082
0.800	0.084	0.087	0.086	0.082	0.081	0.080
1.000	0.082	0.085	0.084	0.080	0.078	0.078

Table 4. Effects of bias b_1 and b_2 on various reproductive estimators for the northern whitebelly spinner dolphin population (*S. longirostris*).

4a. Proportion of mature females.

B_1	Value of B_2 0.00	0.20	0.40	0.60	0.80	1.00
0.000	0.527	0.572	0.609	0.641	0.667	0.690
0.200	0.518	0.563	0.601	0.632	0.659	0.682
0.400	0.511	0.556	0.594	0.625	0.652	0.676
0.600	0.505	0.550	0.588	0.620	0.647	0.671
0.800	0.500	0.545	0.583	0.615	0.642	0.666
1.000	0.495	0.541	0.579	0.611	0.639	0.662

4b. Proportion of nursing calves.

B_1	Value of B_2 0.00	0.20	0.40	0.60	0.80	1.00
0.000	0.261	0.314	0.366	0.418	0.470	0.523
0.200	0.228	0.273	0.319	0.364	0.410	0.455
0.400	0.202	0.242	0.282	0.323	0.363	0.403
0.600	0.181	0.217	0.253	0.290	0.326	0.362
0.800	0.164	0.197	0.230	0.263	0.296	0.328
1.000	0.150	0.180	0.210	0.240	0.270	0.301

4c. Proportion female.

B_1	Value of B_2 0.00	0.20	0.40	0.60	0.80	1.00
0.000	0.509	0.510	0.510	0.511	0.511	0.512
0.200	0.498	0.498	0.498	0.498	0.498	0.498
0.400	0.490	0.489	0.489	0.488	0.488	0.487
0.600	0.484	0.482	0.481	0.480	0.480	0.479
0.800	0.479	0.477	0.475	0.474	0.473	0.472
1.000	0.474	0.472	0.470	0.469	0.467	0.466

4d. Method 1 pregnancy rate.

Value of B_1	
0.000	0.353
0.200	0.378
0.400	0.398
0.600	0.416
0.800	0.430
1.000	0.443

4e. G.A.R. using Method 1 pregnancy rates.

B_1	Value of B_2 0.00	0.20	0.40	0.60	0.80	1.00
0.000	0.095	0.103	0.110	0.116	0.120	0.125
0.200	0.098	0.106	0.113	0.119	0.124	0.128
0.400	0.100	0.108	0.116	0.122	0.127	0.131
0.600	0.101	0.110	0.118	0.124	0.129	0.133
0.800	0.103	0.112	0.119	0.125	0.131	0.135
1.000	0.104	0.113	0.121	0.127	0.132	0.137

Table 5. Effects of bias b_1 and b_2 on various reproductive estimators for the southern whitebelly spinner dolphin population (*S. longirostris*).

5a. Proportion of mature females.

B_1	Value of B_2 0.00	0.20	0.40	0.60	0.80	1.00
0.000	0.639	0.680	0.712	0.739	0.761	0.780
0.200	0.637	0.678	0.711	0.737	0.760	0.778
0.400	0.636	0.677	0.710	0.736	0.759	0.777
0.600	0.635	0.676	0.709	0.735	0.758	0.776
0.800	0.634	0.675	0.708	0.735	0.757	0.776
1.000	0.633	0.674	0.707	0.734	0.756	0.775

5b. Proportion of nursing calves.

B_1	Value of B_2 0.00	0.20	0.40	0.60	0.80	1.00
0.000	0.316	0.380	0.443	0.506	0.569	0.633
0.200	0.278	0.334	0.390	0.445	0.501	0.556
0.400	0.248	0.298	0.348	0.397	0.447	0.497
0.600	0.224	0.269	0.314	0.359	0.404	0.449
0.800	0.204	0.245	0.286	0.327	0.368	0.409
1.000	0.188	0.225	0.263	0.301	0.338	0.376

5c. Proportion female.

B_1	Value of B_2 0.00	0.20	0.40	0.60	0.80	1.00
0.000	0.522	0.523	0.524	0.525	0.526	0.527
0.200	0.512	0.513	0.514	0.514	0.515	0.515
0.400	0.505	0.505	0.506	0.506	0.506	0.506
0.600	0.499	0.499	0.499	0.499	0.499	0.499
0.800	0.495	0.494	0.494	0.494	0.494	0.494
1.000	0.491	0.490	0.490	0.490	0.489	0.489

5d. Method 1 pregnancy rate.

Value of B_1	
0.000	0.295
0.200	0.310
0.400	0.322
0.600	0.332
0.800	0.340
1.000	0.347

5e. G.A.R. using Method 1 pregnancy rates.

B_1	Value of B_2 0.00	0.20	0.40	0.60	0.80	1.00
0.000	0.098	0.105	0.110	0.114	0.118	0.121
0.200	0.101	0.108	0.113	0.118	0.121	0.124
0.400	0.103	0.110	0.116	0.120	0.124	0.127
0.600	0.105	0.112	0.118	0.122	0.126	0.129
0.800	0.107	0.114	0.119	0.124	0.127	0.130
1.000	0.108	0.115	0.120	0.125	0.129	0.132

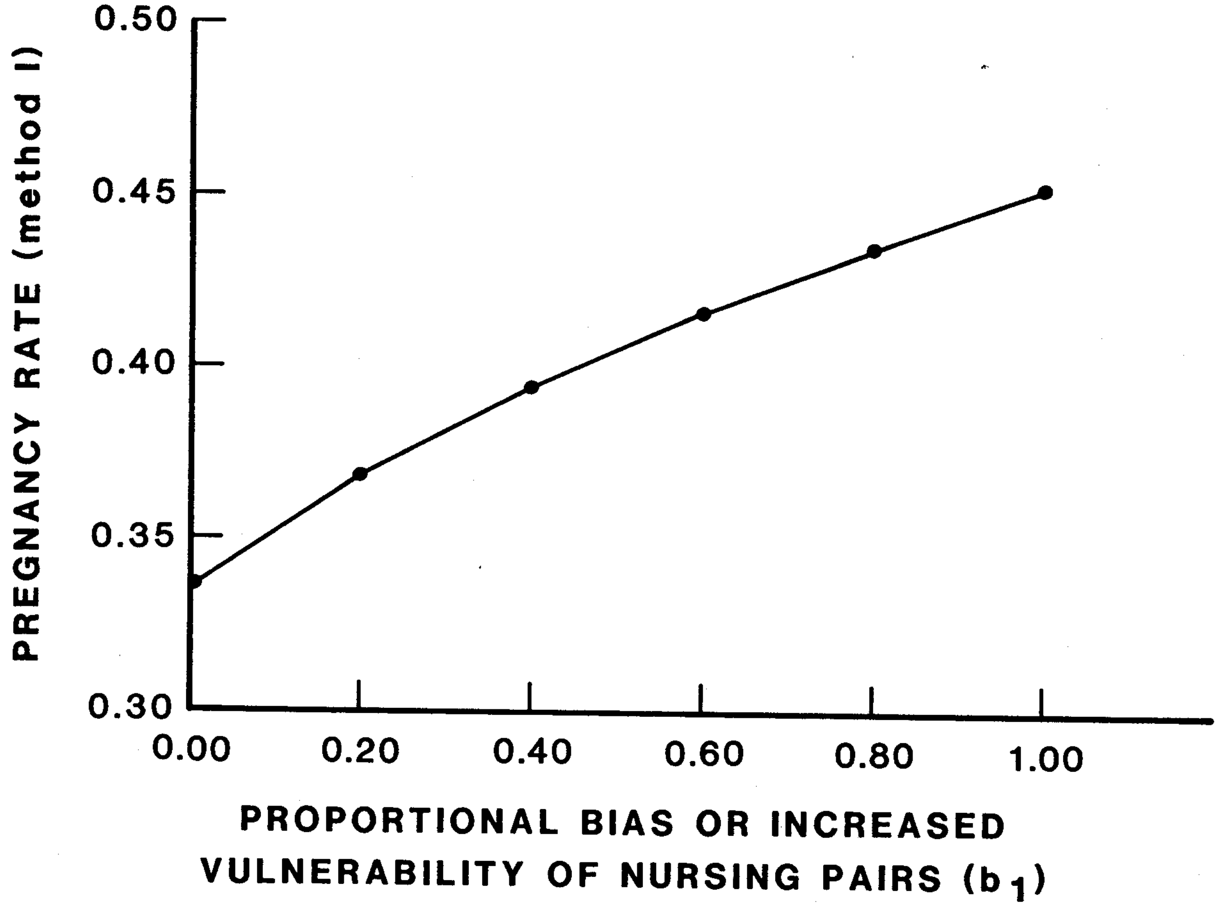

Figure 1. The sensitivity of the pregnancy rate as estimated by Method 1 to bias in the sampling of nursing pairs (b_1) for the pooled data set (1973-1978) for the eastern spinner stock.

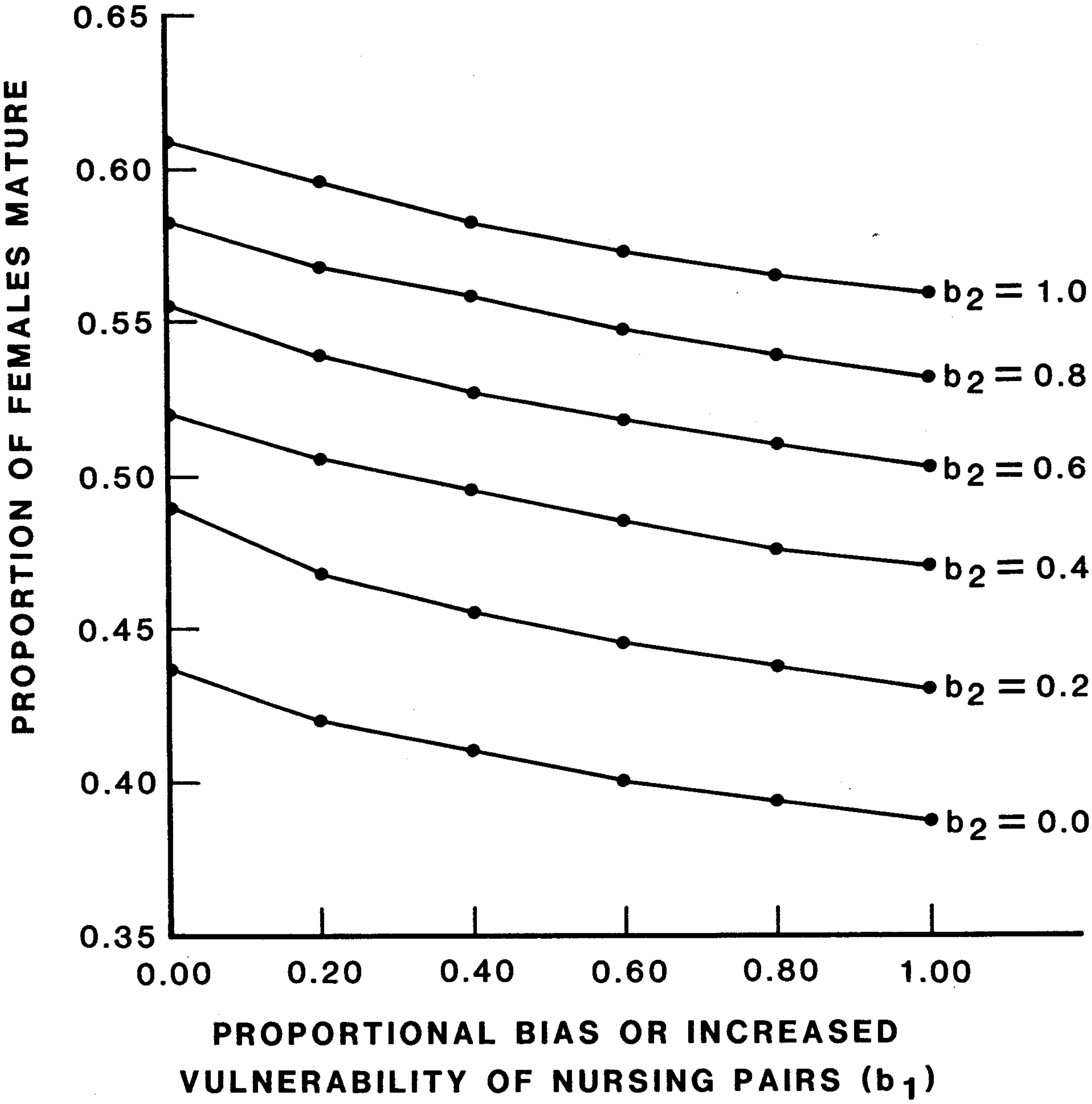

Figure 2. The sensitivity of the proportion mature to biases b_1 and b_2 for the pooled data set (1973-1978) for the eastern spinner stock.

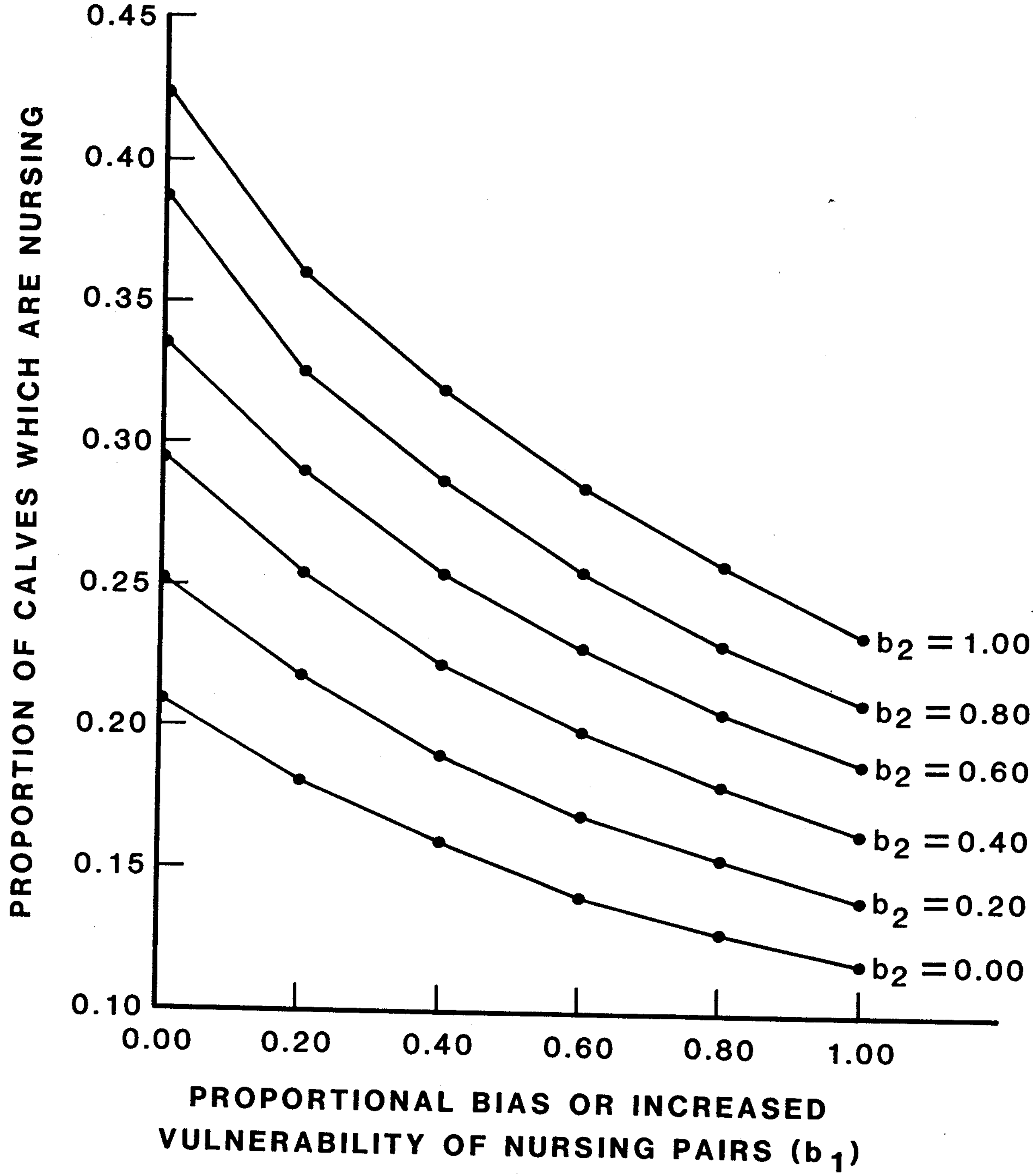

Figure 3. The sensitivity of the estimated proportion of immature nursing female calves to biases b_1 and b_2 for the pooled data set (1973-1978) for the eastern spinner stock.

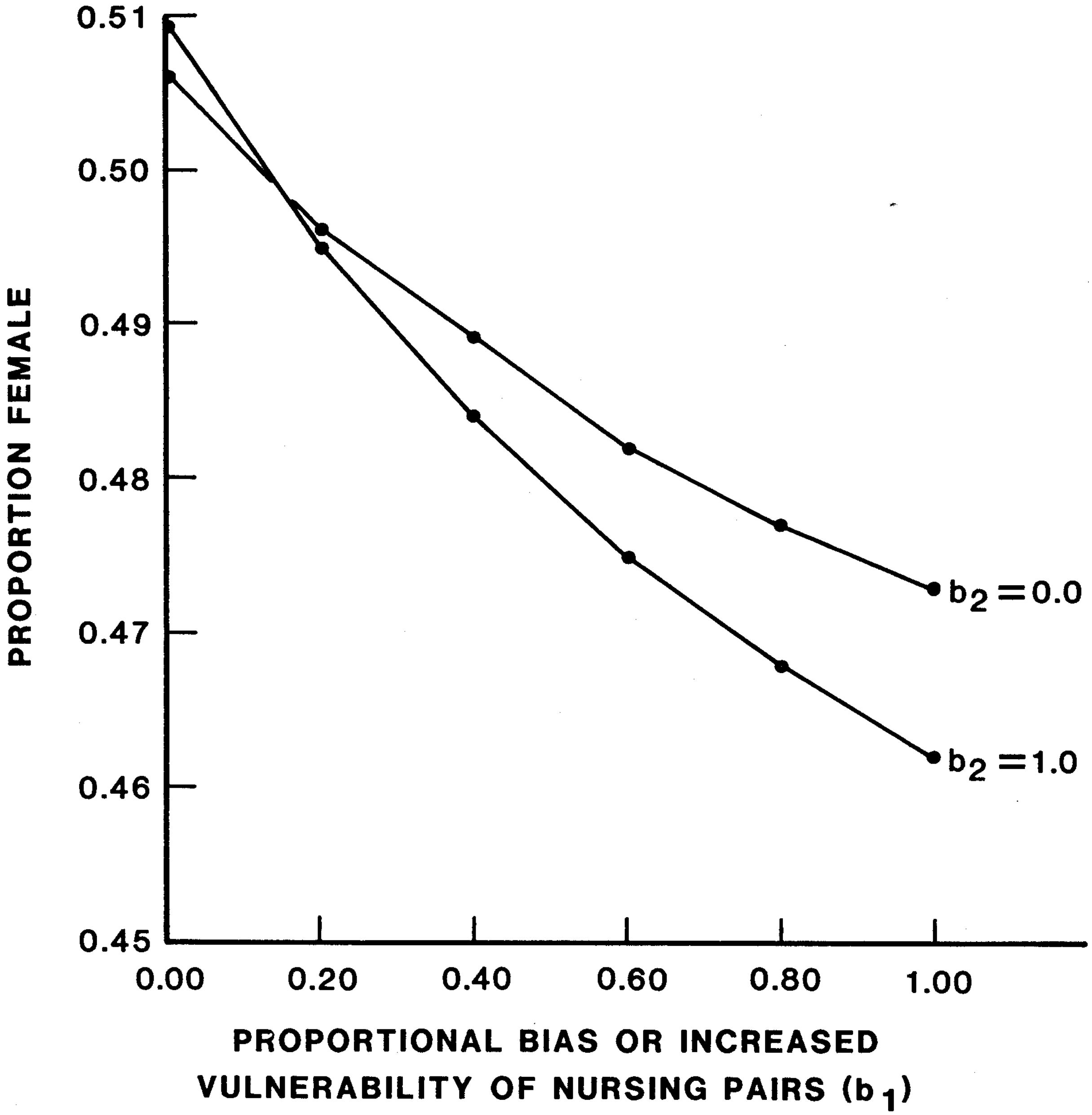

Figure 4. The sensitivity of the estimated proportion of females to biases b_1 and b_2 for the pooled data set (1973-1978) set (1973-1978) for the eastern spinner stock.

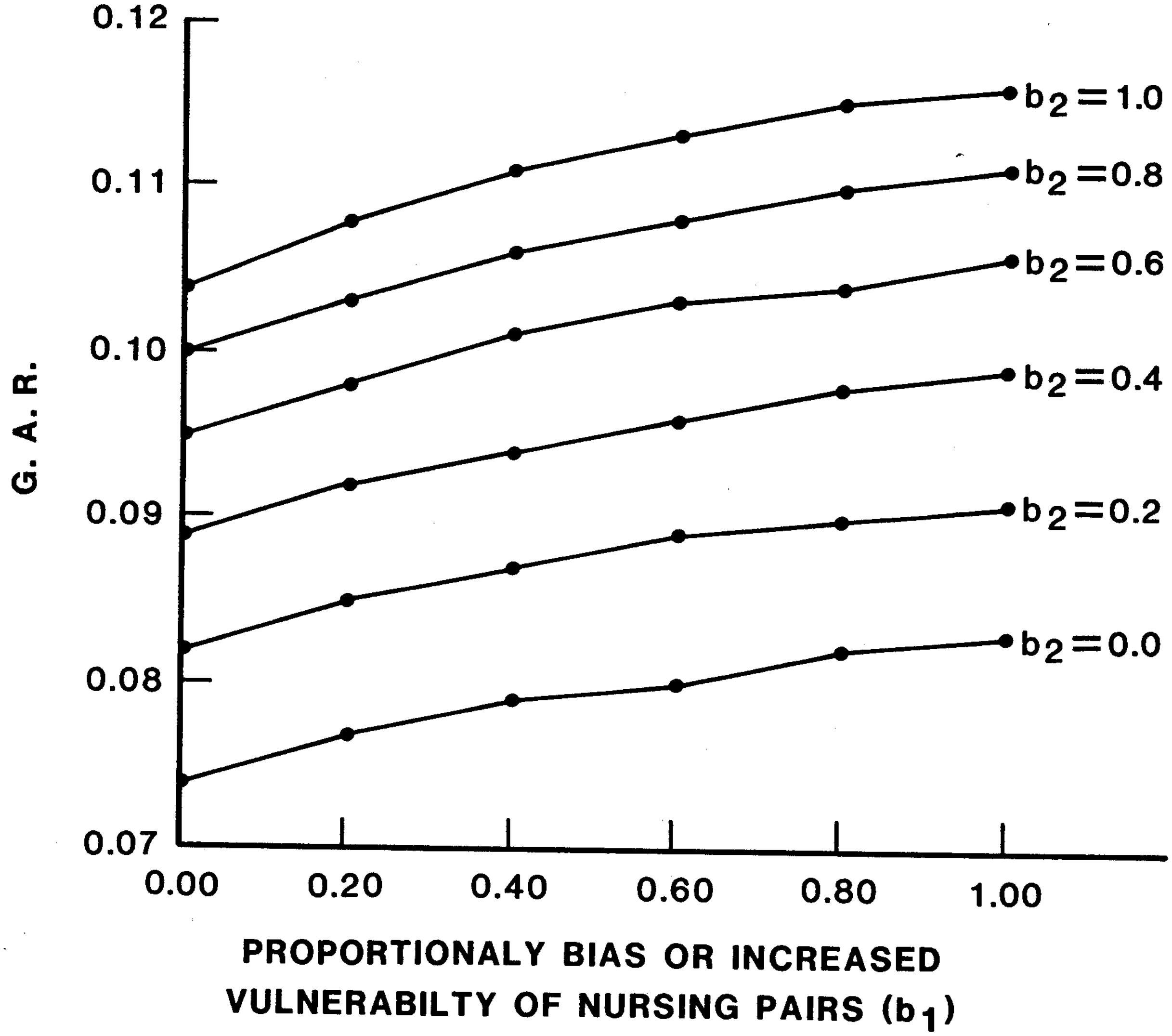

Figure 5. The sensitivity of the estimated gross annual reproductive rate (G.A.R.) using Method 1 pregnancy rates to biases b_1 and b_2 for the pooled data set (1973-1978) for the eastern spinner stock.

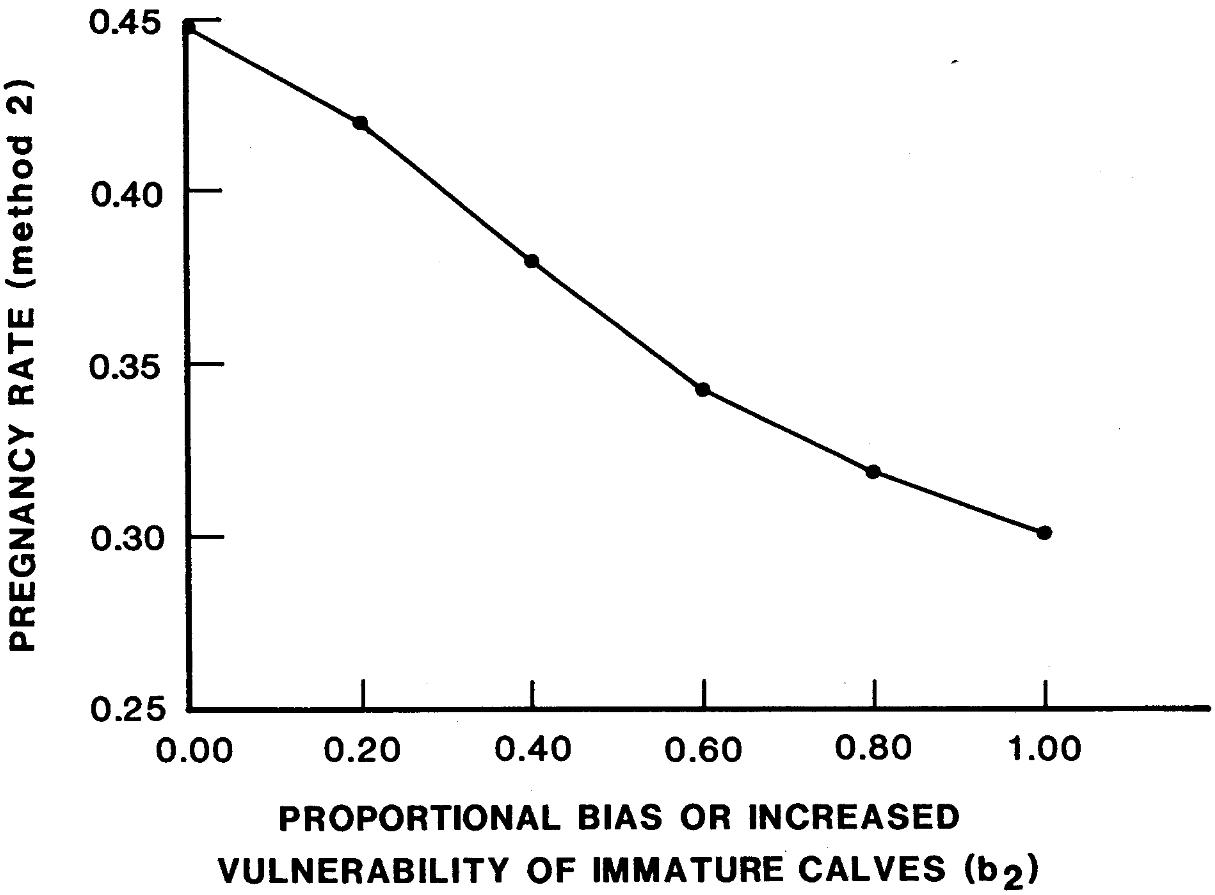

Figure 6. The sensitivity of Method 2 pregnancy rate estimates to bias b_2 for the pooled data set (1973-1978) for the eastern spinner stock.

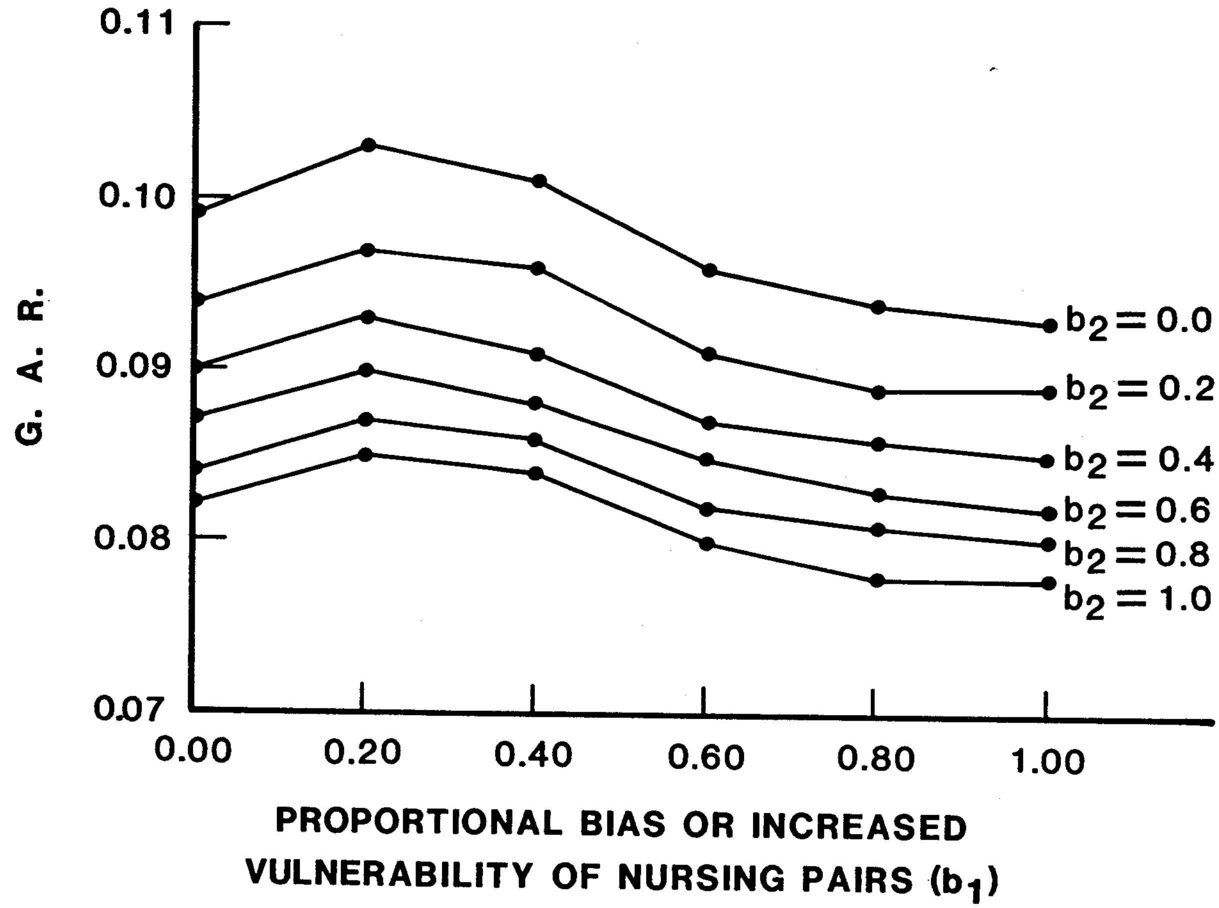

Figure 7. The sensitivity of the estimated gross annual reproductive rate (G.A.R.) using Method 2 pregnancy rates to biases b_1 and b_2 for the pooled data set (1973-1978) for the eastern spinner stock.

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